Evaluación de la calidad acústica de aulas escolares en establecimentos educacionales municipales

Evaluation of the acoustic quality of classrooms in public schools.

Guiselle Estefanía Arroyo Navarro
Filiación: Universidad del Bío-Bío
Dirección: Collao #1202, Concepción CP 4051381
Correo: guiselle.arroyo1601@alumnos.ubiobio.cl

Paulina Wegertseder Martínez
Filiación: Universidad del Bío-Bío
Dirección: Collao #1202, Concepción CP 4051381
Correo: pwegertseder@ubiobio.cl

Manuscript Code: 010

Date of Acceptance/Reception: 06.07.2018/31.05.2018

Resumen
Esta investigación evalúa la calidad acústica de cuatro aulas escolares ubicadas en Temuco (Chile) con el mismo sistema constructivo y entorno de ruido ambiental. Tres aulas tienen vidrio simple, diferentes alturas y terminaciones interiores, la otra tiene doble vidrio hermético (DVH) y tratamiento acústico. La calidad acústica se analizó con mediciones in-situ y encuestas basadas en el tiempo de reverberación (RT), inteligibilidad de la palabra (STI), porcentaje de perdida de la consonante (%Alcons) y ruido de fondo (L_{eq}). Las mediciones in-situ se guiaron a través del estándar internacional ISO-3382, utilizando el aula en estado desocupado. Los resultados fueron comparados con los estándares nacionales Términos de Referencia estandarizados (TDRe) e internacionales DB-HR Código Técnico de la Edificación de España (CTE), Instituto de estándar nacional de Estados Unidos (ANSI) y el Boletín de la construcción 93 de Reino Unido (BB93) los que muestran una mala calidad acústica para los 3 primeros casos y buena para el ultimo. Esto contribuye a mejorar la calidad acústica de las aulas a través del uso y distribución de materiales adecuados.

Palabras claves: Calidad Acústica; Aulas escolares; Medición in-situ.

Abstract
This research evaluates the acoustic quality of four classrooms located in Temuco (Chile) with the same constructive system and environmental noise. Three classrooms have single pane glass and different interior heights and surfacing materials. The other one has double pane glass and acoustic treatment. The acoustic quality was analyzed via on-site measurements and questionnaires based on the reverberation time (RT) speech intelligibility (STI) loss of consonant (%Alcons) and background noise (L_{eq}). The on-site measurement was guided by the international standard ISO-3382 using an unoccupied classroom. Results have been compared with the national standars Terminos de referencia estandarizados (TDRe) and international DB-HR Código Tecnico de la Edificación from Spain (CTE) Acoustical National Standard Institute from USA (ANSI) and Building bulletin 93 from United Kingdom (BB93) that reaveal poor acoustical quality for the first three cases and good for the last one. This contributes to improve the acoustic quality of the classrooms by correctly using the interior surfacing materials.

Keywords: Acoustic Quality; Classrooms; On-site measurement

Introduccion

In the last 10 years the noise level of Temuco has increased and public schools in Chile are not governed by an acoustic regulation that specifies the appropriate ranges for classroom acoustics. The classroom environmental conditions play crucial roles in health, performance and behavior of students (Vilcekova et al., 2017). When teachers communicate with or give instructions to the students in the classrooms, it is important that the messages can be passed effectively and clearly between them (Tang & Yeung, 2006). Among many aspects of interest for sustainability improvement in schools, acoustic comfort plays a primary role for students learning ability and teacher's health. Recently, research in the acoustic field was focused on listening quality and on noise effects in learning environments. A good acoustic environment is primarily achieved by the minimization of the contributions of noise from external and internal sources (Puglisi et al., 2015). The architectural factors and the constructive characteristics of the classrooms has an influence on the acoustic quality measured on the inside. The porpuse is to diagnose the acoustic quality of four classrooms from different public schools according to the predominant constructive system in scenarios with similar environmental noise. One of them has acoustic treatment. Another focus was the evaluation of the student perception through questionnaires. The acoustical parameters like reverberation time, speech intelligibility, lost of consonant and background noise have been measured following the international standard ISO-3382 (ISO 3382-2, 2008)

Estado del arte del problema

In order to achieve a good level of speech intelligibility, even in small classrooms, an accurate prediction of the reverberation time and speech level is necessary (Astolfi, Corrado, & Griginis, 2008). In practical terms, for school design, there is a need for guidance on considering the voice in classrooms, and whether passive room design can influence voice parameters (Durup Ab, Shield, Dance, Sullivan, & Gomez-Agustina, 2015). There are no substantial evaluations or improvement suggestions available now. One should not ignore the impact of the school environment on children, since they spend about one-third of their day at school. Their hearing, learning, and physical and mental health will be affected if they are in an inappropriate environment for a long time (Chiang & Lai, 2008). Reverberation time is a measure of the degree of reverberation in a space and is equal to the time required for a constant sound to decay into 60 dB after the sound source has ceased and is expressed in seconds (s). When the reverberation time has high values, it becomes difficult to distinguish sounds and understand speech because the syllables will overlap and interfere with intelligibility (Terra Vasconcelos Rabelo, Nunes Santos, & Cristina Oliveira, 2014). The results of Bradley tend to suggest that these indices are highly correlated with each other, implying that they are in principle equivalent for the purpose. The speech intelligibility is affected by the background noise, but the noise exposure of the children and teachers has been shown to have other additional impacts on the teaching and learning process (Tang, 2007). In practice and research the reverberation as an indicator of acoustic quality it is one of the most used to do measurements on-site and have an important impact in the acoustic comfort from the students and teachers.

Metodología

Case studies

This was a descriptive and experimental analysis through the on-site measurement. Four public schools were selected with the same constructive system and environmental noise but with different type of glazing and interior surfacing materials (Table 1).

Table 1. Classrooms features. Prepared by the author, 2018.

CONSTANTS FACTORS		DYNAMIC FACTORS	
ENVIRONMENTAL NOISE	70 - 80 dB	SURFACING MATERIAL	PLASTER BOARD - PAINTED SURFACE - WOODEN PLANKS
CONSTRUCTIVE SYSTEM	REINFORCED CONCRETE	HEIGHT	3.2m - 2.8m - 3.07m - 3.25m
TYPE OF GLAZING	SINGLE PANE	GLASS AREA	$21m^2$ - $14m^2$ - $11m^2$ - $16m^2$
AREA	45 - 55 m^2		

With the chosen factors was identified four representative classrooms, one of each school and they were named type A, B, C and D as follows on table 2 with associated constructive characteristics. The classrooms were chosen with the door in front of the hall and the windows in front an avenue with 70 – 80 dB of environmental noise.

Table 2. Schools: Case studies. Prepared by the author, 2018.

TYPE	SCHOOL	CONSTRUCTIVE SYSTEM	ABSORBENT SURFACE	AREA	HEIGHT	GLASS AREA	TYPE OF GLASS	SURFACING MATERIAL		
								WALLS	CEILING	FLOOR
A	ANDRES BELLO	REINFORCED CONCRETE	191.17 m^2	51.9 m^2	3.2 m	21.1 m^2	SINGLE PANE	WOODEN PLANK	WOODEN PLANK	PARQUET
B	LOS TRIGALES	REINFORCED CONCRETE	194.27 m^2	51.7 m^2	3.1 m	14.7 m^2	SINGLE PANE	PLASTERBOARD	PLASTERBOARD	VINYL
C	MILLARAY	REINFORCED CONCRETE	173.36 m^2	46.6 m^2	2.9 m	11.3 m^2	SINGLE PANE	PLASTERBOARD/POLIGYP	PLASTERBOARD	VINYL
D	PABLO NERUDA	REINFORCED CONCRETE	187.83 m^2	48.8 m^2	3.2 m	16.4 m^2	DOUBLE PANE	ACOUSTIC TREATMENT	PLASTERBOARD	VINYL

Acoustical measurement

The acoustic quality of the classrooms was evaluated with measurement of acoustic parameters such as reverberation time, speech intelligibility, lost of consonant and background noise. A long reverberation time is inappropriate for places such as classrooms, because the reflected sound will remain a form of reverberation longer than ideal, interfering with the direct sound and reducing intelligibility. Also, it will cause unwanted sounds, such as dragging of chairs and foot movements, which will also remain longer in the room, increasing noise levels (Terra Vasconcelos Rabelo et al., 2014).. The reverberation time was evaluated using the impulsive noise method by popping balloons in six different combinations between microphone and source, acoording to the method impulse response from ISO 3382. An omnidirectional microphone model C03 multi-pattern was used in the field at a height of 1 meter from the floor. The ballon was popped at 1.5 meter simulating the height of the teacher's mouth. The results were analyzed by the Audio Real Time Analysis (ARTA) software. The reverberation time values were obtained for each frequency but the result is a single value from the arithmetic mean for the frequencies of 500, 1.000 and 2.000 Hz. The instruments used in the measurements had their calibration certificates. For the background noise a sonometer model 52 certificate: 10714.2 class 1 was used. The position of the balloons (G) and the microphones (M) are shown in Figure 1 to 8.

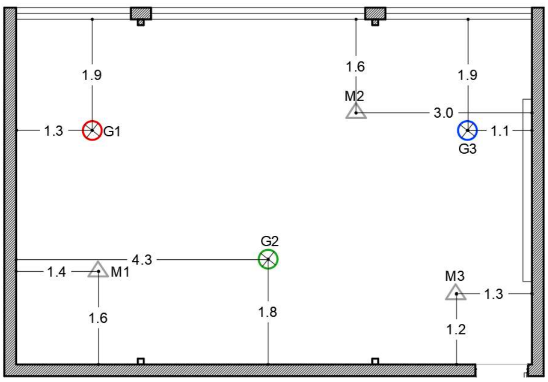


Figure 1. TYPE A. Source and microphone position. Prepared by the author, 2018.

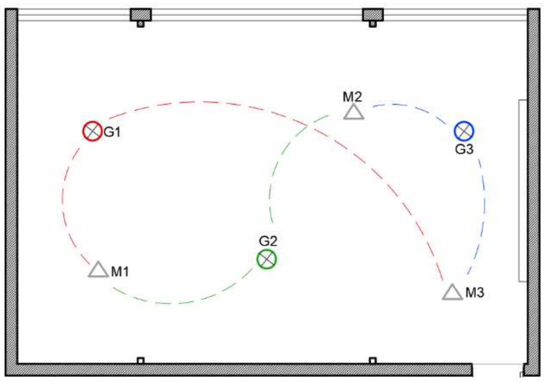


Figure 2. TYPE A. Source and microphone combination. Prepared by the author, 2018.

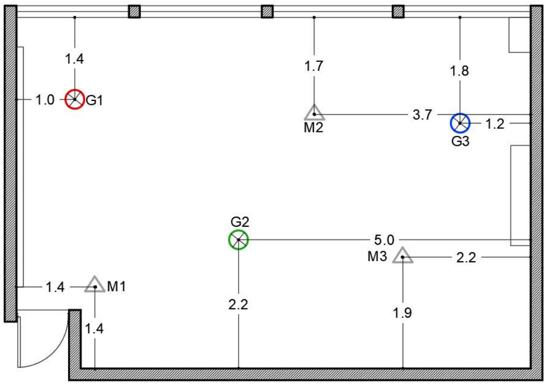


Figure 3. TYPE B. Source and microphone position. Prepared by the author, 2018.

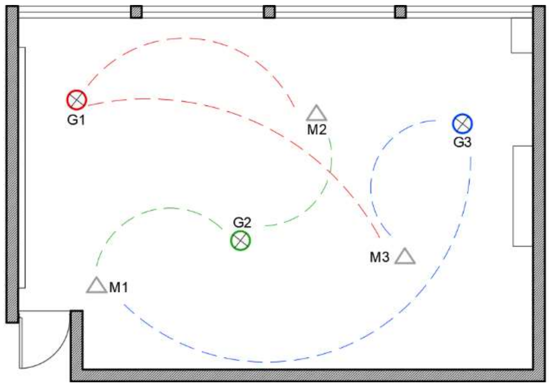


Figure 4. TYPE B. Source and microphone combination. Prepared by the author, 2018.

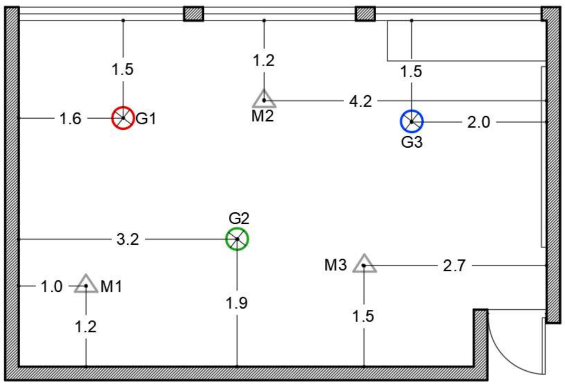


Figure 5. TYPE C. Source and microphone position. Prepared by the author, 2018.

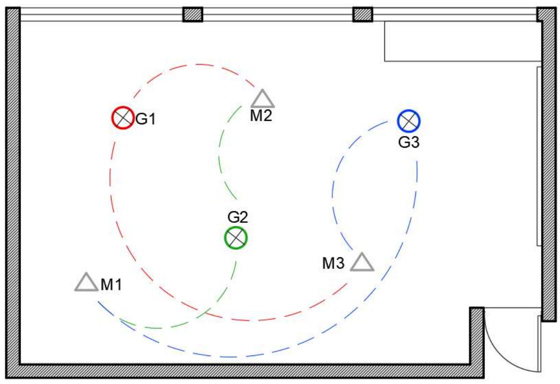


Figure 6. TYPE C. Source and microphone combination. Prepared by the author, 2018.

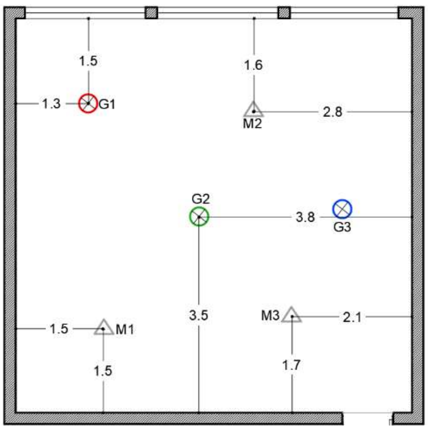


Figure 7. TYPE D. Source and microphone position. Prepared by the author, 2018.

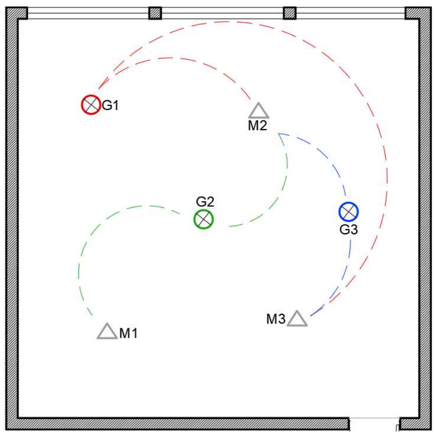


Figure 8. TYPE D. Source and microphone combination. Prepared by the author, 2018.

Questionnaires

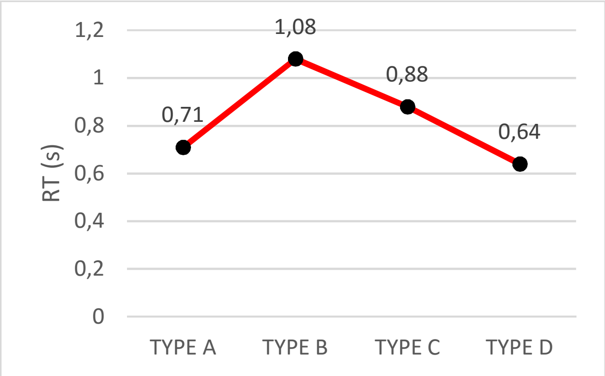
The student's perceptions were analyzed through questionnaires. The questions were related to influence of external noises, background noise in the classroom, the teacher's speech, the comfort percent and the clarity of the teacher's speech. The results obtanined in the questionnaires complements the results on the on-site measurements and show the relation between these two parameters.

Resultados

Quantitatve anlaysis: on-site measurement

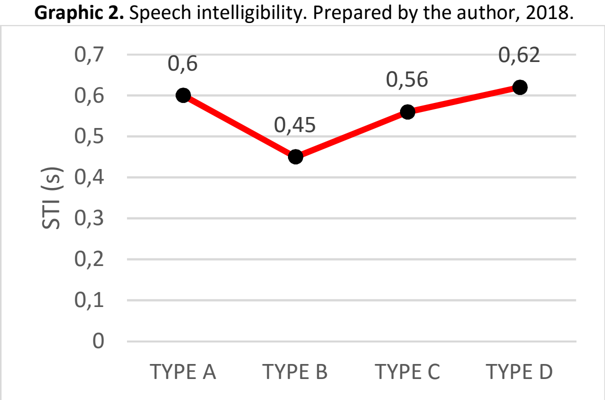
Results of the reverberation time (Graphic 1) in their different combinations for each classroom expected results according to the observation on-site where classroom type A has a better RT compared to type B and C considering that the surfacing materials are different. For type D that has acoustic treatment the results are accepted by the standards. The four types were compared with national and international standards as follow on Table 3.

Graphic 1. Reverberation time on-site. Prepared by the author, 2018.



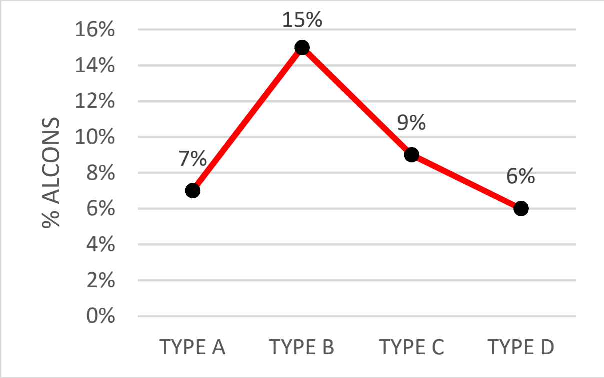
STI measurements (Graphic 2) and %Alcons (Graphic 3) was analyzed through the results of the reverberation time with ARTA software that shows results according to the impulse noise measured on-site. The values do not exceed the standards TDRe, ANSI and BB93 for the types A and D. For type B and C, the results are in the recommendations specified by the ANSI standard only.

Graphic 2. Speech intelligibility. Prepared by the author, 2018.



5° Congreso Sudamericano de Simulación de Edificios / 27-28 Septiembre 2018 / Valparaiso (Chile)
Palme, M., Lobos, D., Robles, C. (Ed.) Ibpsa Latam 2018:Libro de Artículos ISBN: 978-956-398-316-6
IBPSA Chile https://sites.google.com/view/ibpsachile

Graphic 3. Lost of consonant. Prepared by the author, 2018.



For the background noise the results (Graphic 4) were measured with a soundemeter in six differents positions. The value for each classroom is the mean for the results of the six measurements. The levels of ambient noise measured in the different classrooms were higher than recommended by the standards (Table 3).

Graphic 4. Background Noise. Prepared by the author, 2018.

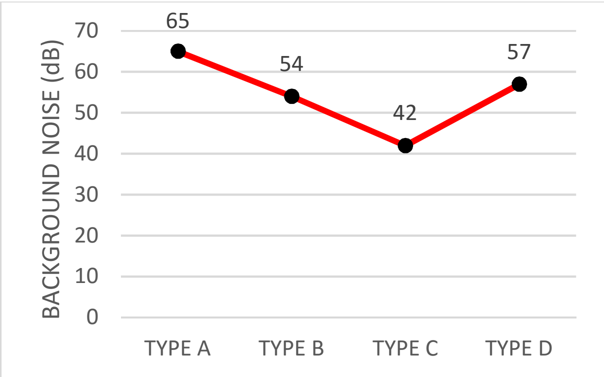


Table 3 shows the comparison between the on-site measurements results and the standards according to the quantitative analysis

Table 3. National and international standards. Prepared by the author, 2018.

TYPE	RT	TDRe	CTE	ANSI	BB93	STI	TDRe	CTE	ANSI	BB93	L_{eq}	TDRe	CTE	ANSI	BB93
A	0.71	x	x	x	✓	0.60	✓	/	✓	✓	46.5	/	/	x	x
B	1.08	x	x	x	x	0.45	x	/	✓	x	43.3	/	/	x	x
C	0.88	x	x	x	x	0.56	x	/	✓	x	39.7	/	/	x	x
D	0.64	✓	✓	✓	✓	0.62	✓	/	✓	✓	40.7	/	/	x	x

Qualitative analysis: questionnaires

In the questionaires the parameters associated with classroom acoustic quality were evaluated with the results from the measurements made on-site. In the type A and D, the comfort percent is higher showing that those who have the RT between ranges that the standards recommend, have a better acoustic quality. In type B and C, the percent of clear hearing is lower and is related to the STI and the RT who are below the standars. The tendencies are shown on Table 4.

Table 4. Qualitative analysis: Tendencies. Prepared by the author, 2018.

TYPE	CLASSROOM NOISE	TEACHER'S SPEECH	ENVIRONMENTAL NOISE		HEARS AN ECHO
			AVENUE	HALL	
	% COMFORT	**% CLEAR HEARING**	**% COMFORT**		**% AFFIRMATION**
A	83%	80%	51%	74%	34%
B	45%	51%	56%	85%	79%
C	46%	65%	58%	71%	61%
D	90%	84%	88%	51%	27%

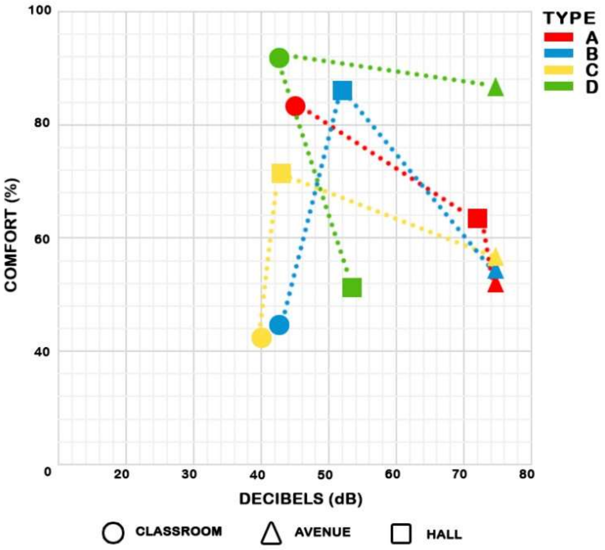
Comparison between quantitative and qualitative analysis

In general, it was observed that the acoustic quality of classrooms according to the perception of the students is connected to the clarity of hearing from the teacher's speech and when the environmental noise from the outside does not affect them. Comparing with the on-site measurements the results shows that type A and D are closer to the standards recommendations demonstrating the conexion with the percent of comfort from the students and the levels of discomfort from the environmental noise.

Comparing the results of Table 3 and 4, the background noise of the classroom, the hall and the exterior is related to the percentage of acoustic comfort that the student has with the noise on the inside, the avenue and the hall. Type A has a background noise of 47 dB and 83% of comfort, this decreases when the noise comes from the hall considering the 65 dB and the single pane glass on that side of the classroom. Type B has a background noise of 43 dB and 45% of comfort, this increases to 85% when the noise comes from the hall because that side of the classroom does not have windows. Type C has a background noise of 40 dB and 46% of comfort. Type D has background noise of 41 dB and 90% of comfort, indicating that the classroom has good acoustic quality according to the results of both measurements. This combination of variables is shown in Graphic 5.

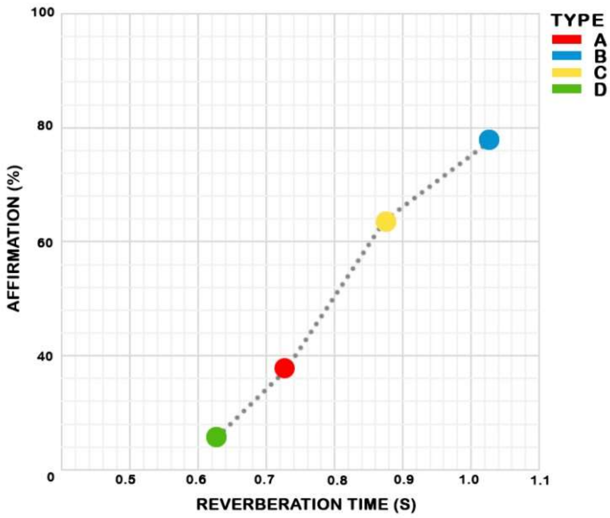
5° Congreso Sudamericano de Simulación de Edificios / 27-28 Septiembre 2018 / Valparaiso (Chile)
Palme, M., Lobos, D., Robles, C. (Ed.) Ibpsa Latam 2018:Libro de Artículos ISBN: 978-956-398-316-6
IBPSA Chile https://sites.google.com/view/ibpsachile

Graphic 5. Background noise and comfort. Prepared by the author, 2018.



In Graphic 6, results of the qualitative analysis are shown as the percentage of affirmation of the students in listening to an echo in the classroom, this was compared with the RT measured on-site. The optimum reverberation time for a classroom is 0.6 s. Type D has RT 0.64 s that despite being on the recommendations suggested by the standards, only 34% of the students consider that there is an echo in the classroom. In type B, the reverberation time is 1.08 s, wich is above the recommended standards and is complemented by 79% of the students that declare to hear an echo.

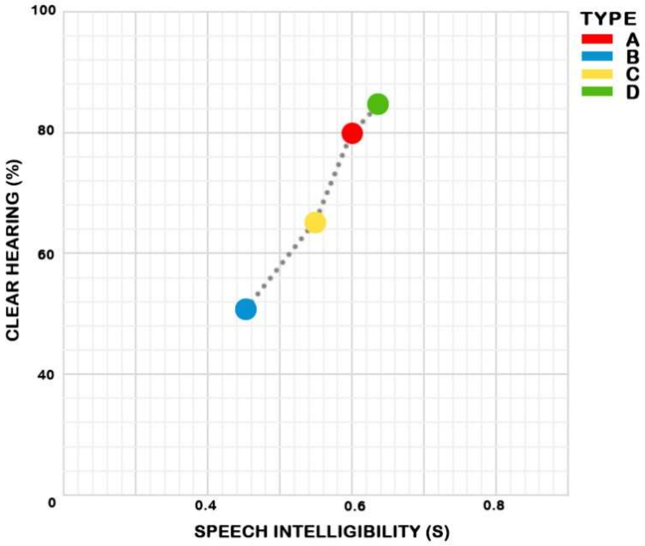
Graphic 6. Reverberation time and echo affirmation. Prepared by the author, 2018.



5° Congreso Sudamericano de Simulación de Edificios / 27-28 Septiembre 2018 / Valparaiso (Chile)
Palme, M., Lobos, D., Robles, C. (Ed.) Ibpsa Latam 2018:Libro de Artículos ISBN: 978-956-398-316-6
IBPSA Chile https://sites.google.com/view/ibpsachile

In Graphic 7 the STI is shown that type A and D has a major percentage of clear hearing and a value of 0.60 s and 0.62 s that are within the ranges established by TDRe, ANSI and BB93. This is associated with the surfacing materials of the classrooms and the acoustic conditions.

Graphic 7. Speech intelligibility and clear hearing. Prepared by the author, 2018.



Discusión y Conclusiones

From the obtaneid results in the two types of measurements, poor acoustical quality was revealed on the analysis of reverberation time, speech intelligibility, loss of consonant and background noise. The influence of the environmental noise is critical when the classrooms has single pane glass. The reverberation time is better when the surfacing materials of the walls has a better acoustic quality such as wood. Although the background noise found in classrooms was higher tha the maximum level recommended by the standards TDRe, ANSI, CTE and BB93. The STI is related to the RT, if the RT is 0.6 or less and the STI is higher than 0.6 s, a better acoustic quality is obtained.

The measured classrooms do not provide an environment of quality for students, the acoustic signal must be transformed into a clear message.

A different situation happens when the classroom has an acoustic treatment, the results of the quantative and qualitative analysis show the importance of considering the acoustic quality in the design stage. Thus, it recommends on existing classrooms to change the single pane glass for double pane glass, use wooden planks instead of plastearboard in all surfaces, avoid windows in walls that facing halls.

it is expected that further studies can do a simulation with acoustic softwares from this data and recommendations to keep improving the acoustic quality of the classrooms.

Agradecimientos

The author would like to thank the students and the schools administrators for they generous assistance and all the people involved in this study.

Referencias

Astolfi, A., Corrado, V., & Griginis, A. (2008). Comparison between measured and calculated parameters for the acoustical characterization of small classrooms. https://doi.org/10.1016/j.apacoust.2007.08.001

Chiang, C.-M., & Lai, C.-M. (2008). Acoustical environment evaluation of Joint Classrooms for elementary schools in Taiwan. Building and Environment, 43, 1619–1632. https://doi.org/10.1016/j.buildenv.2007.10.014

Citec UBB. (2015). Téminos de referencia estandarizados (TDRe), 2.

Daniels, R., Freemantle, A., Mukund, P. (2014). Building Bulletin 93. ACOUSTIC DESIGN OF SCHOOLS. Retrieved from http://webarchive.nationalarchives.gov.uk/20130402164558/https://www.education.gov.uk/publications/eOrderingDownload/BB93-Acoustic_Design.pdf

Durup Ab, N., Shield, B., Dance, S., Sullivan, R., & Gomez-Agustina, L. (2015). How classroom acoustics affect the vocal load of teachers. Energy Procedia, 78, 3084–3089. https://doi.org/10.1016/j.egypro.2015.11.761

Fomento, M. De, & Decreto, R. (2010). Codigo Técnico Español. documento Básico HR: Protección frente al ruido, 2010.

ISO 3382-2. (2008). Incorporating corrigendum Acoustics-Measurement of room acoustic parameters- Part 2: Reverberation time in ordinary rooms, 2009, 2008–2009.

Puglisi, G. E., Cantor Cutiva, L. C., Pavese, L., Castellana, A., Bona, M., Fasolis, S., … Astolfi, A. (2015). Acoustic comfort in high-school classrooms for students and teachers. Energy Procedia, 78, 3096–3101. https://doi.org/10.1016/j.egypro.2015.11.763

Standard, A. N. (2009). Acoustical performance criteria, design requierements and guidelines for schools, part 2.

Tang, S. K. (2007). Speech related acoustical parameters in classrooms and their relationships. https://doi.org/10.1016/j.apacoust.2007.08.008

Tang, S. K., & Yeung, M. H. (2006). Reverberation times and speech transmission indices in classrooms. JOURNAL OF SOUND AND VIBRATION, 294, 596–607. https://doi.org/10.1016/j.jsv.2005.11.027

Terra Vasconcelos Rabelo, A., Nunes Santos, J., & Cristina Oliveira, R. (2014). Effect of classroom acoustics on the speech intelligibility of students. CoDAS, 2626(55), 360–6360. https://doi.org/10.1590/2317-1782/20142014026

Vilcekova, S., Meciarova, L., Burdova, E. K., Katunska, J., Kosicanova, D., & Doroudiani, S. (2017). Indoor environmental quality of classrooms and occupants' comfort in a special education